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Engelhard Corporation

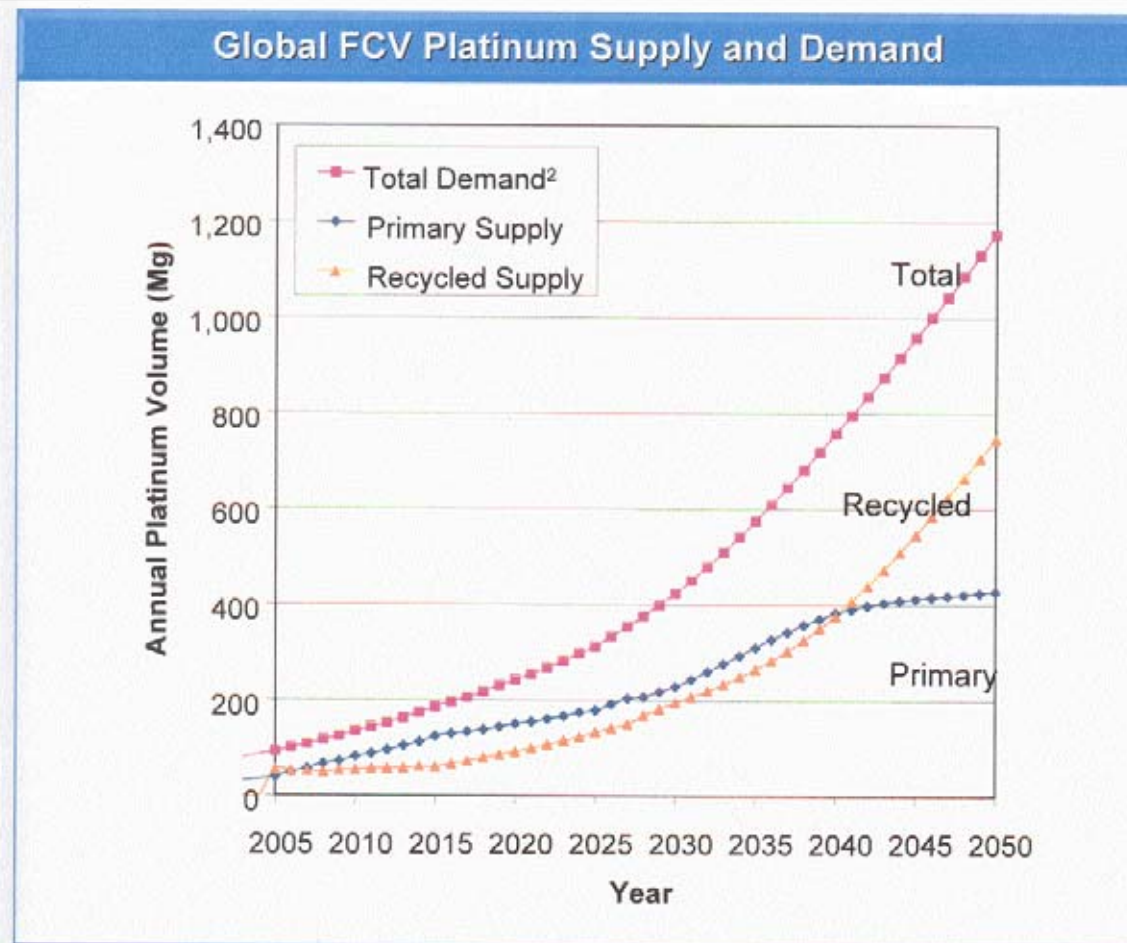
May 25, 2004

**Platinum Group Metal Technology
Development**
DE-FC36-03GO13104

This presentation does not contain
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ENGELHARD

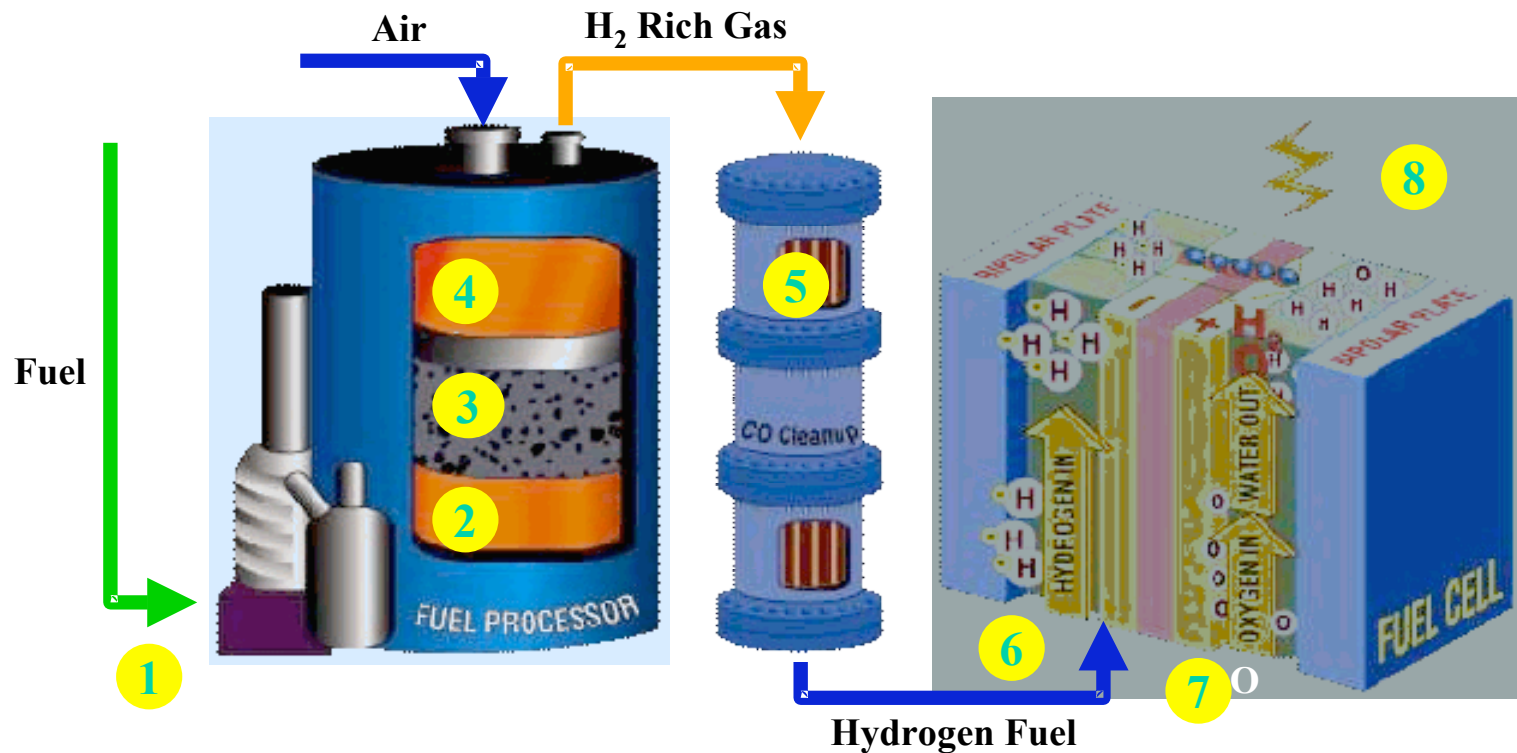
Pt Recycling is Crucial to Successful Implementation of Fuel Cells




Recycling will supply the bulk of Pt required in 2050

Refiners, like Engelhard, become 'miners'

Schematic of a Fuel Cell System With Reformer



- | | | |
|-------------------------------|-------------------|--------------------|
| ① Sulfur Removal | ④ Water Gas Shift | ⑦ Cathode |
| ② Catalytic Partial Oxidation | ⑤ PROX | ⑧ Emission Control |
| ③ Steam Reforming | ⑥ Anode | |



Objectives of DOE Pt Recycling Project (Started 11/2003)

Recycle all PM-containing catalysts in a fuel cell 'system'

- **Develop a commercially-acceptable, environmentally-friendly process for recovering and recycling Pt and Ru from membrane electrode assemblies (MEAs)**
 - **Develop a process that does not emit pollutants, especially HF**
 - **Evaluate Ru recovery from MEA's**
- **Develop a process for PM recovery from metal monoliths**
- Maximize precious metal (PM) yield from ceramic catalysts

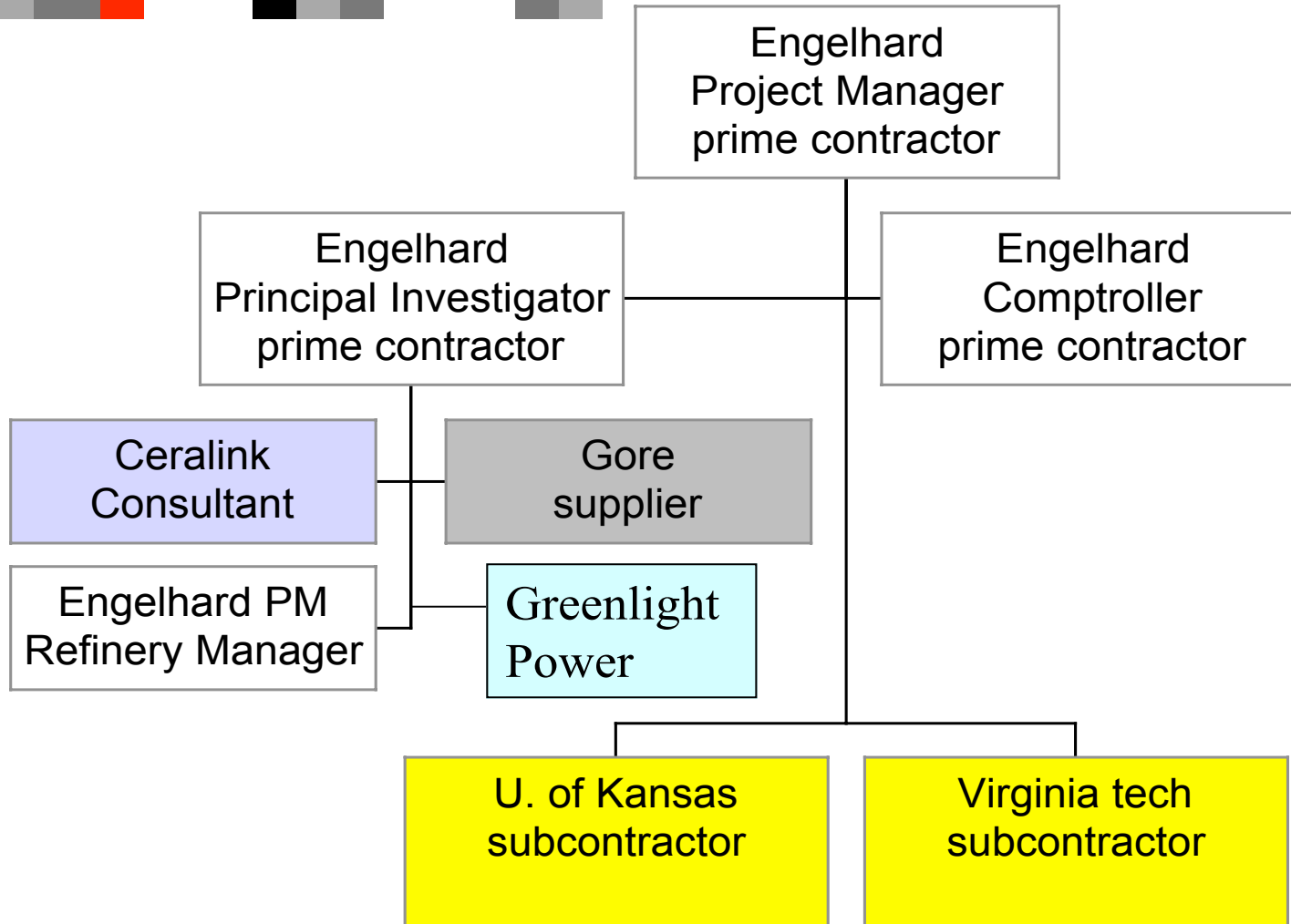
*Principal objectives in **bold**.*



What Makes a Refining Process Commercially Acceptable?

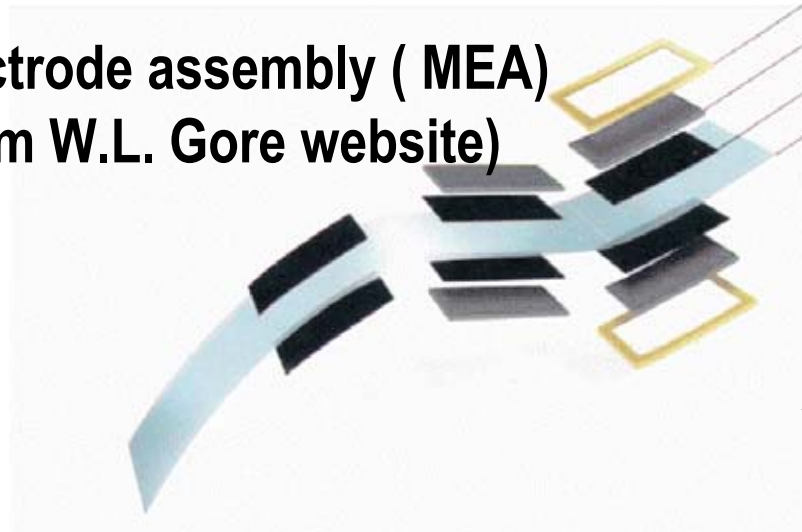
- **Process must permit quantification of the precious metal content of lot (weigh, sample, analyze)**
- **Precious Metal Recovery Meets or Exceeds Industry Standard**
- **Processing Cost is comparable to reference method**
- **Safety Concerns are Minimal**

Organization Chart for Precious Metal Recovery/Recycling Project

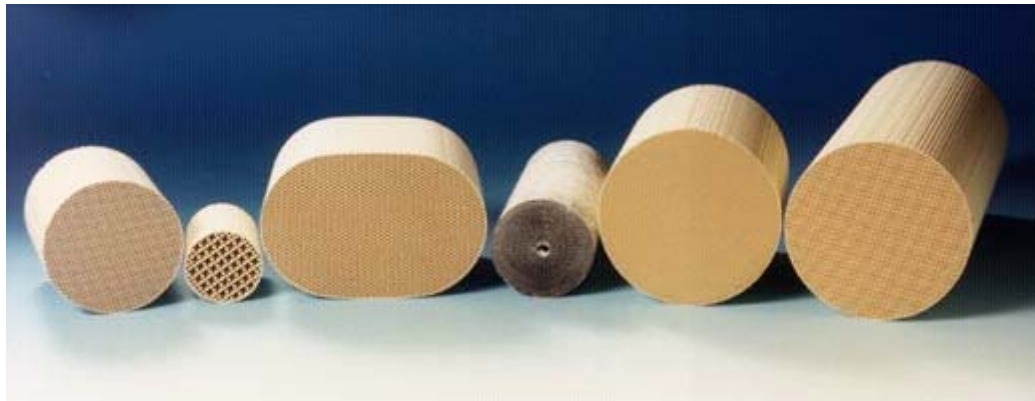


Examples of Fuel Cell Catalysts

Membrane electrode assembly (MEA) (Adapted from W.L. Gore website)



Gasket
Gas diffusion layer
Cathode catalyst
Nafion membrane
Anode catalyst



**Honeycomb monoliths
(ceramic) - Used
in a fuel cell reformer**

Budget for DOE Project No. DE-FC36-03GO13104

FY2003	\$375,000	\$300,000	\$75,000.00
FY2004	\$681,250	\$545,000	\$136,250
FY2005	\$875,000	\$700,000	\$175,000
FY2006	\$1,625,000	\$1,300,000	\$325,000
FY2007	\$1,513,995	\$1,211,700	\$302,295
FY2008	\$900,000	\$720,000	\$180,000

Engelhard has a 20% cost share obligation



Technical Barriers and Targets

- Address barriers N (Cost) and O (Stack Material and Manufacturing Cost) of the HFCIT Program Multi-Year R&D Plan.
- Meet DOE technical targets for 2010 for fuel cell power systems
 - \$45/kW cost target for Transportation
 - Direct hydrogen
 - Reformer-based operating on low-sulfur gasoline
 - \$400 – 700/kw for Stationary
 - PEM fuel cell system operating on natural gas or propane



Overview of Technical Approach

- Develop environmentally-friendly processes for recovering and recycling the precious metals present in PEM fuel cell stacks and fuel reformers.
 - Investigate
 - leaching
 - industrial microwave methods
 - super critical carbon dioxide

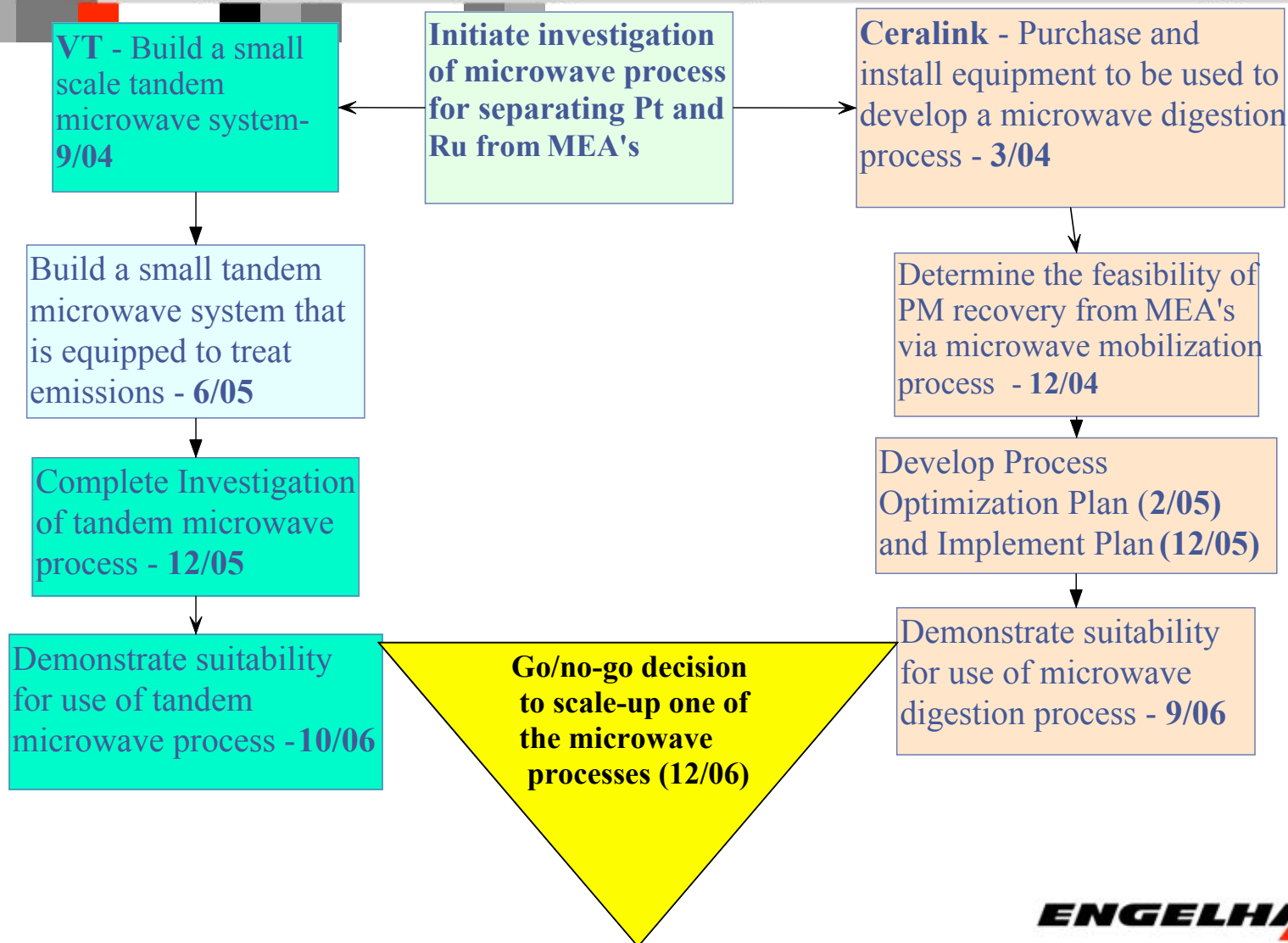
and select the preferred processes for recovering precious metals from the various types of catalysts present in PEM fuel cell systems
- **Build and operate pilot equipment to demonstrate process viability (Primary deliverable)**
- Estimate the economics of viable processes



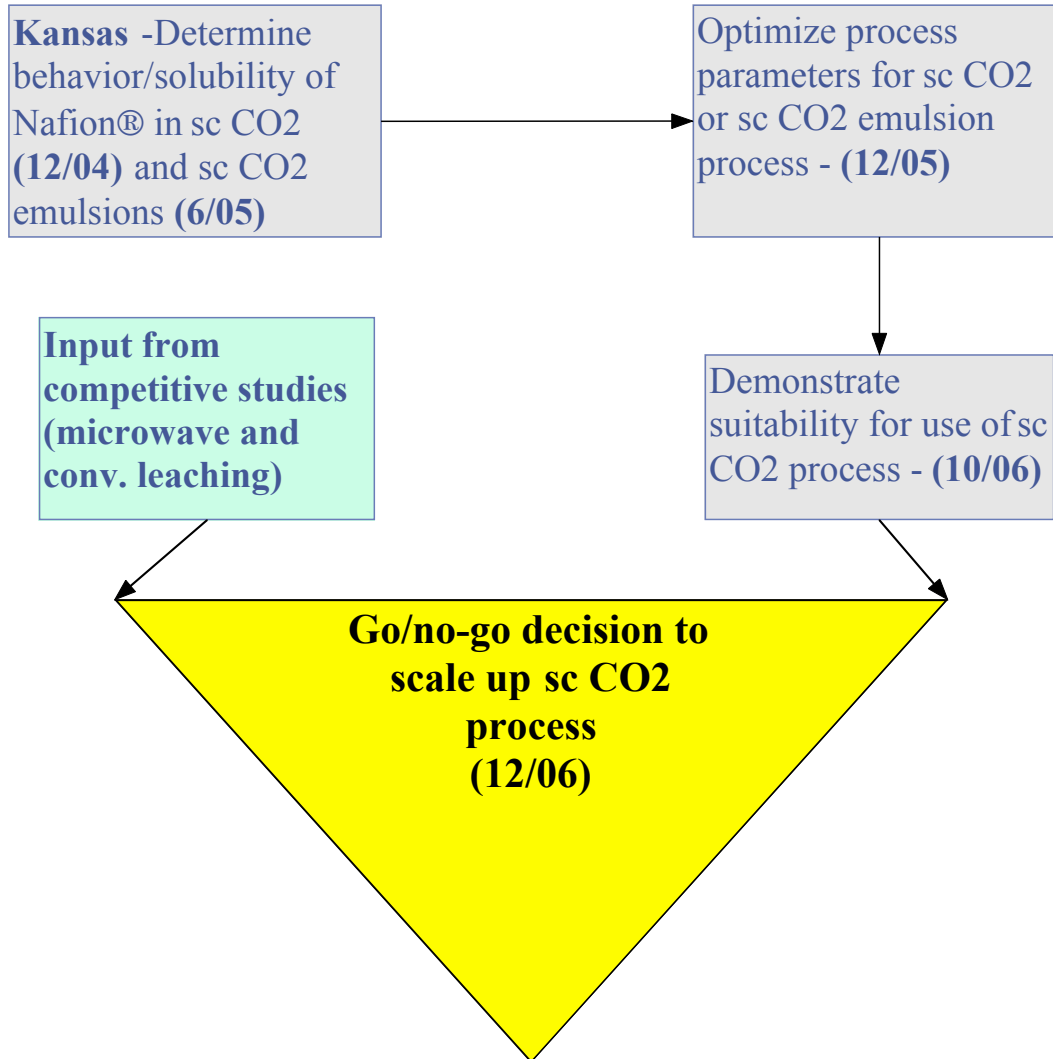
Safety Issues Related to the Pt Recycling Project

- Microwave Techniques
 - Microwave leakage
 - Electrical Shock for capacitor
 - HF formation
 - Overheating
- Supercritical Fluid Techniques
 - System under pressure
- Leach Techniques
 - Corrosive fumes
- Use a microwave leak detector and safety interlocks
- use proper insulation
- Properly vent and/or scrub exhaust fumes
- Monitor temperature
- Use Plexi-glass shields for protection
- Properly vent and/or scrub fumes

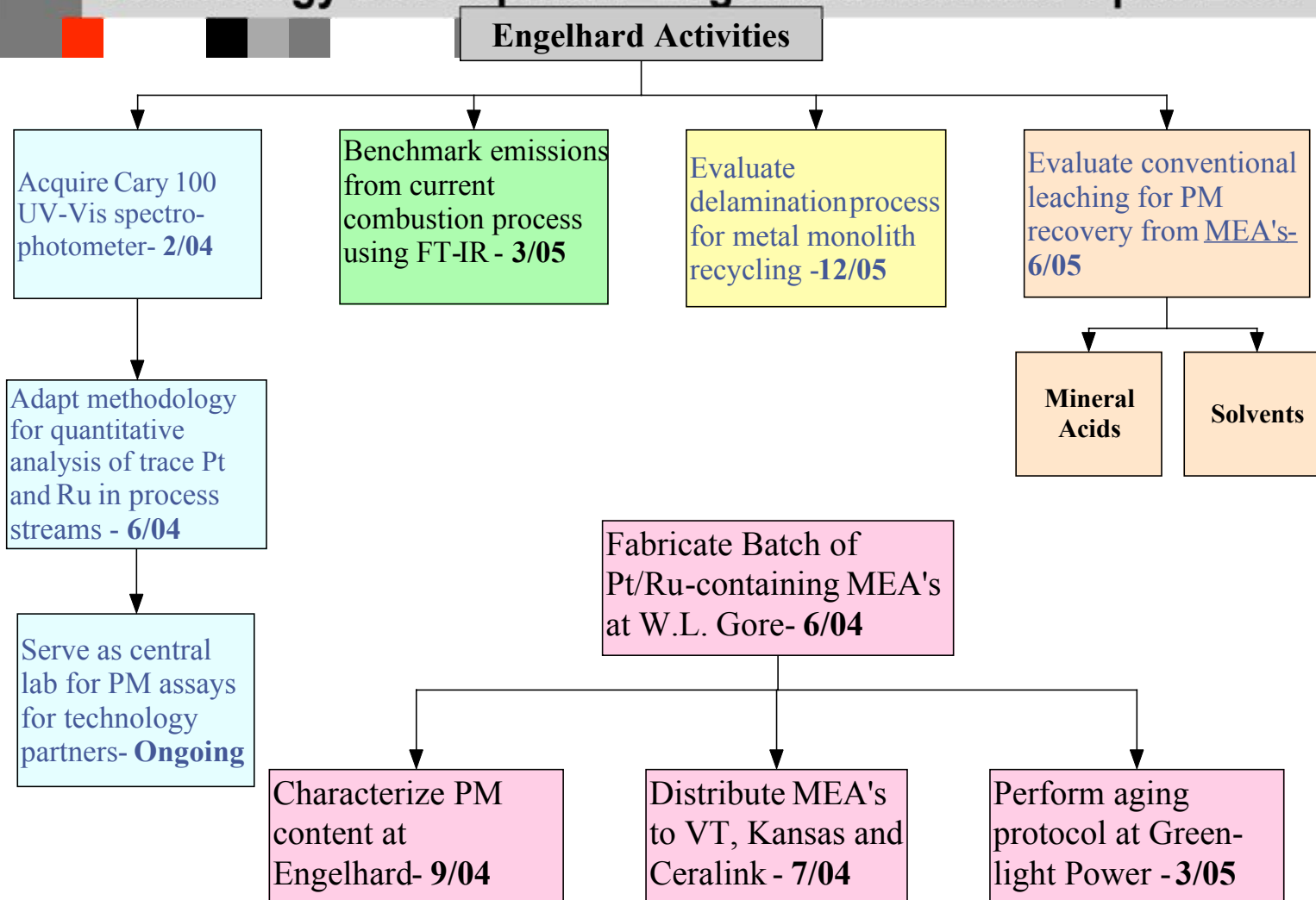
Milestone Schedule for Platinum Group Metal Recycling Technology Development – Microwave Approach



Milestone Schedule for Platinum Group Metal Recycling Technology Development- SC CO2 Approach



Milestone Schedule for Platinum Group Metal Recycling Technology Development- Engelhard Activities Up to 2006





Milestone Schedule for Platinum Group Metal Recycling Technology Development- Engelhard Activities For 2006-2008




Task	Due Date
Place Order for large batch of MEA's	1/1/2006
Accept delivery of MEA's	6/1/2006
Estimate preliminary process cost	10/1/2006
Engineering plans for pilot plant due	12/15/2006
Final estimate of process cost	3/1/2007
Order Equipment for demonstration plant	4/1/2007
Build demonstration plant	12/1/2007
Demonstration plant operational	6/1/2008



MEA Aging of Gore-fabricated MEA's

- Greenlight Power will assemble a stack and
 - Age with reformat using a stationary source cycle
 - Acquire electrochemical performance
 - Withdraw cells at 500, 1000 and 1500 hours for testing
 - Harvest the remainder at 2000 hours
- The suitability of proposed recovery methodology to aged MEA's will be determined
- Ruthenium migration across membrane will be evaluated through time lapse sampling of the stack



Major accomplishments In 1st year

- VT – Thermal Destruction of MEA with microwave energy
- Ceralink – Delamination of 3- and 5-layer MEA's
- University of Kansas – Construction of apparatus for phase studies
- Gore – Fabrication of MEA batch (end of 2nd quarter)
- Engelhard – Developing practical method for Pt and Ru determination with quantitative recovery



Materials Science and Engineering



4 Layered Sheets on Alumina Plate

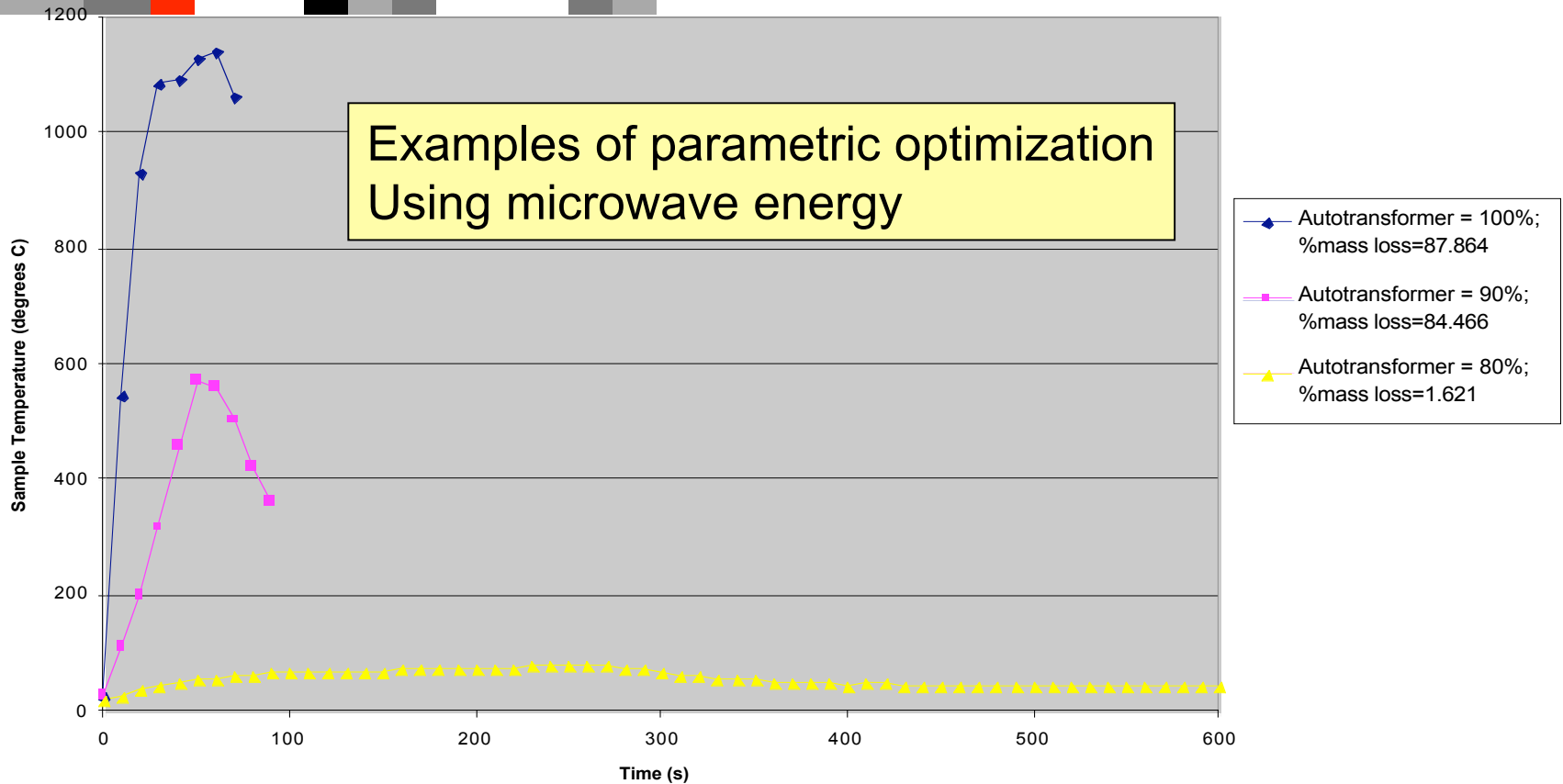


Figure 1. Results of microwave firing of three samples of 3-ply catalyst-coated Nafion stacked 4 sheets high on a microwave-transparent substrate.



Future Work (2004-2005)



- VT
 - Continue temperature versus time runs with MEA samples.
 - Transfer residues to Engelhard to assay Pt content and ash composition
 - Build a microwave unit with effluent treatment capability
- University of Kansas –
 - Continue phase analysis studies to determine favorable solvent system for Nafion.
- Ceralink
 - Evaluate acidic media and microwave conditions for optimizing precious metal recovery from MEA's



Acknowledgement to Our Technology Partners

- Corporate - Project Administration and technical services
- Seneca - Refining expertise and facilities
- **Virginia Tech, Blacksburg, VA (Diane Folz, David Clark and Carlos Suchicital)**
Development of emission-free process involving microwave decomposition and sequestration of hazardous volatiles
- **Ceralink, Alfred, NY (Holly Shulman) - Microwave assisted leaching of PM from Nafion**
- **University of Kansas, Lawrence KA (Bala Subramaniam) - Supercritical fluid treatment of MEA's to dissolve Nafion and permit separation of PM phase from Nafion**
- W.L. Gore, Elkton, MD - Supplier of MEA's
- Green Light Power, Vancouver, BC- Testing of stacks to generate aged MEA's